Above-the-MUF Propagation and JT65/FT8 Advantages Over CW
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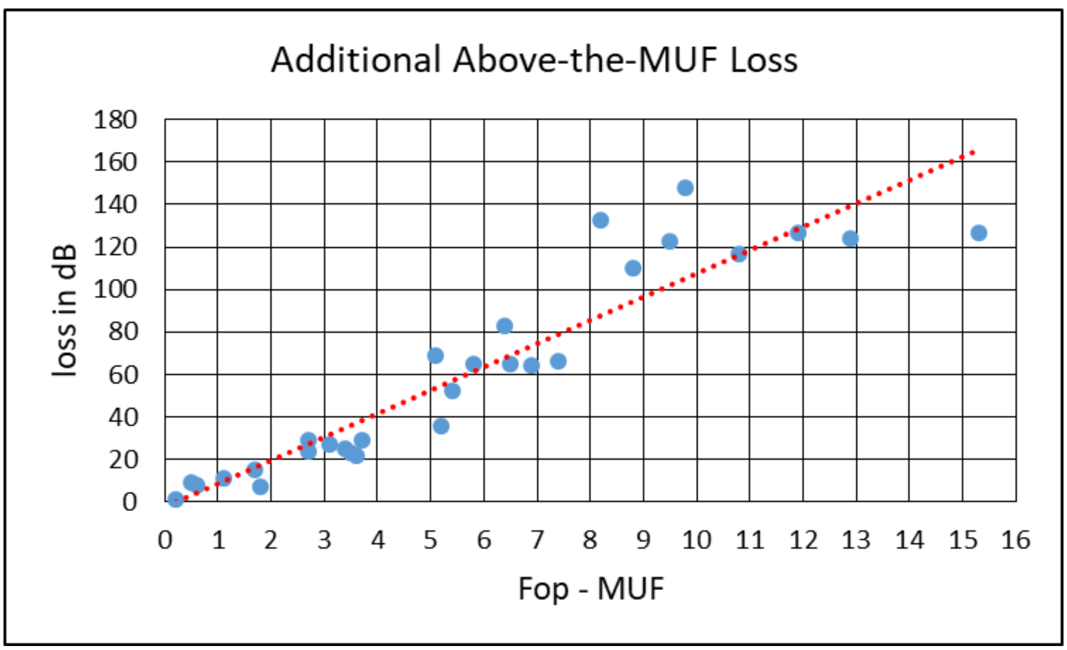
My October 2017 QST article (Understanding Propagation with JT65, JT9 and FT8) about the advantage of the JT65 and FT8 digital modes over CW focused on what is called the "above-the-MUF" mode (MUF is short for maximum useable frequency). An above-the-MUF mode exists in the real world, and this mode says that communication can still occur even if the operating frequency is above the MUF. When the operating frequency is below the MUF, pure refraction occurs. When the operating frequency is above the MUF, some form of scatter may still allow the QSO to be completed. Although the scatter process results in additional loss, JT65 and FT8 may still result in a QSO if CW doesn't get through.

The Above-the-MUF algorithm in VOACAP

To see how much additional loss is involved, we can extract the loss in dB versus the difference between the operating frequency (Fop) and the MUF by running VOACAP predictions over a given path at various smoothed sunspot numbers. The above-the-MUF algorithm in VOACAP is based on Phillips-Abel theory (J. L. Wheeler, *Transmission Loss of Ionospheric Propagation Above the Standard MUF*, **Radio Science**, Vol. 1, No. 11, November 1966). Going thru this exercise with VOACAP gives the following plot.

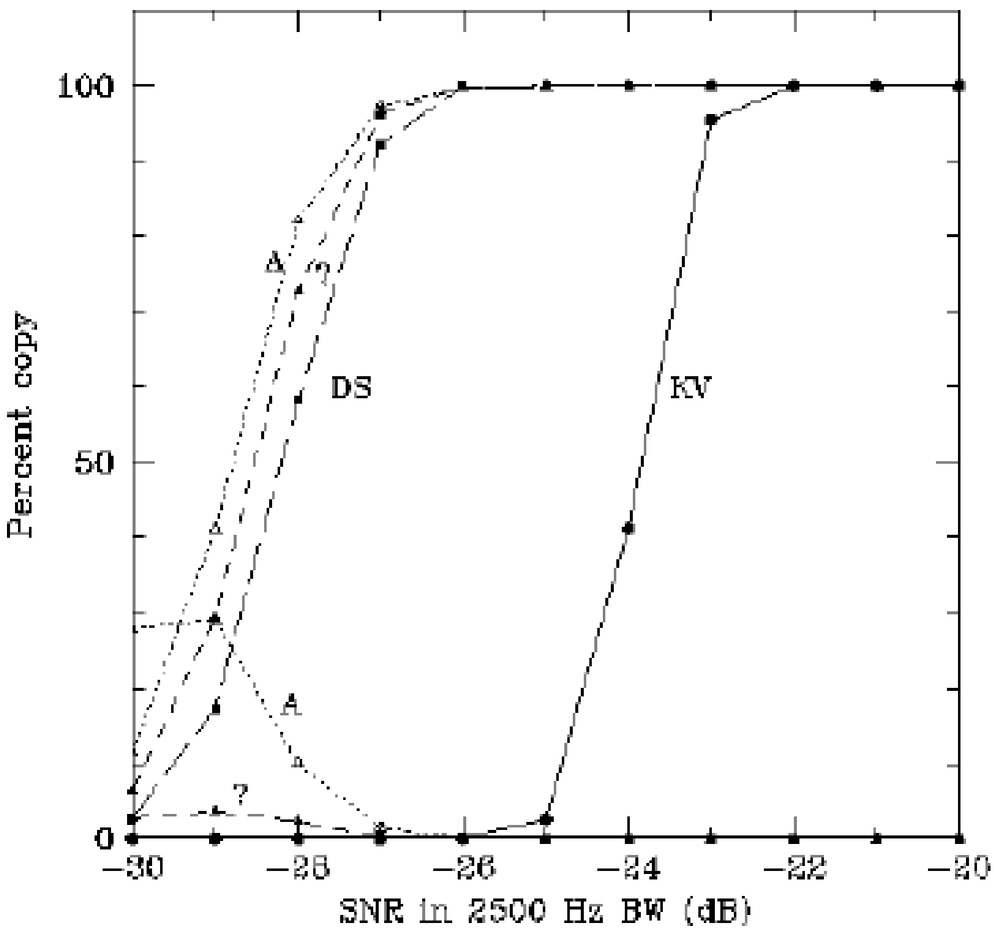


The data points from VOACAP are the blue dots. I've added a linear trend line (red dots) to the data to allow us to more easily estimate the additional loss incurred based on how much the MUF is below the operating frequency. The spread of data points about the trend line is small when the difference between Fop and the MUF is small. As the difference increases, the spread also increases. Thus we should use caution when the difference between Fop and the MUF is great.

Theoretical Advantage of JT65 and FT8 over CW

In my October 2017 QST article, I also made a very cursory analysis of the advantage of JT65 and FT8 over CW. Let's do a more rigorous analysis to try to pin it down better.

The following is Figure 4 in the "JT65 Communications Protocol" document (page 15) by Joe Taylor K1JT. It shows percent copy versus SNR in dB for JT65 in a 2500 Hz bandwidth.



The KV curve uses the Koetter-Vardy (KV) algorithm to decode. The DS curve is the deep search (DS) algorithm, which uses a list of plausible call signs and grid locators to aid in the decoding process.

For my analysis of the advantage of JT65 over CW, I will use the KV data (no a priori knowledge of who you might be working). From the above figure, for all intents and purposes, a 100% probability of decoding JT65 is accomplished at an SNR of -23 dB (in the 2500 Hz bandwidth.

From Table 16.1 in the WSJT-X User Guide (page 63 – also by Joe Taylor), it is stated that FT8 is 4 dB worse than JT65. Summarizing these two results gives:

mode	bandwidth	probability	SNR threshold
JT65	2500 Hz	100%	-23 dB (KV)
FT8	2500 Hz	100%	-19 dB

Now let's look at CW in a 250 Hz bandwidth. At what SNR can a typical operator copy CW under this condition? My estimate in my QST article was 0 dB. Is that reasonable? Let's go one step further here – what can I copy in 250 Hz?

To determine this, I used a homebrew 7.061MHz crystal oscillator, a 60 dB fixed attenuator and a step attenuator with my OMNI-VI.

First I measured the MDS (minimum discernible signal – also known as the noise floor) of my OMNI-VI on 40-Meters with the 250 Hz filter selected. It was -136 dBm in 250 Hz. When the signal from the oscillator is at the MDS, the voltage out of the headphone jack (or across the speaker terminals) increases by 3 dB. This signifies that the signal is at the same level as the noise – which is an SNR of 0 dB.

At this 0 dB SNR, the signal was weak but I could copy the signal perfectly (I keyed the oscillator using its ON/OFF switch). So I began adding in more attenuation. I could still copy the signal 100% with an additional 2 dB of attenuation, but another 1 dB more attenuation resulted in significant degradation. So I personally could copy perfectly at an SNR of -2 dB.

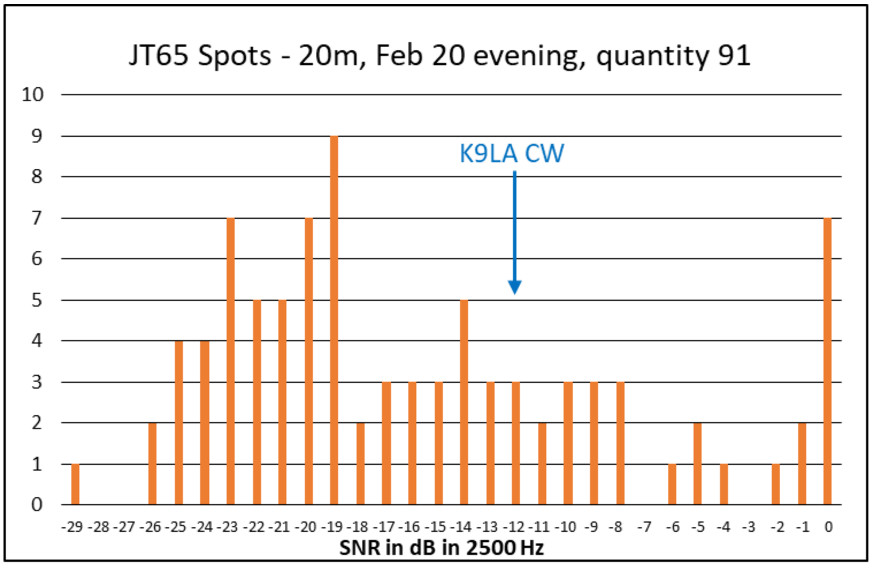
Now we can translate the 250 Hz CW SNR to a 2500 Hz SNR to compare to JT65 and FT8. This is done by noting that 10 x log [250/2500)] = -10, and thus a -2 dB SNR in 250 Hz is a -12 dB SNR in 2500 Hz. Let's add this data point to the previous table.

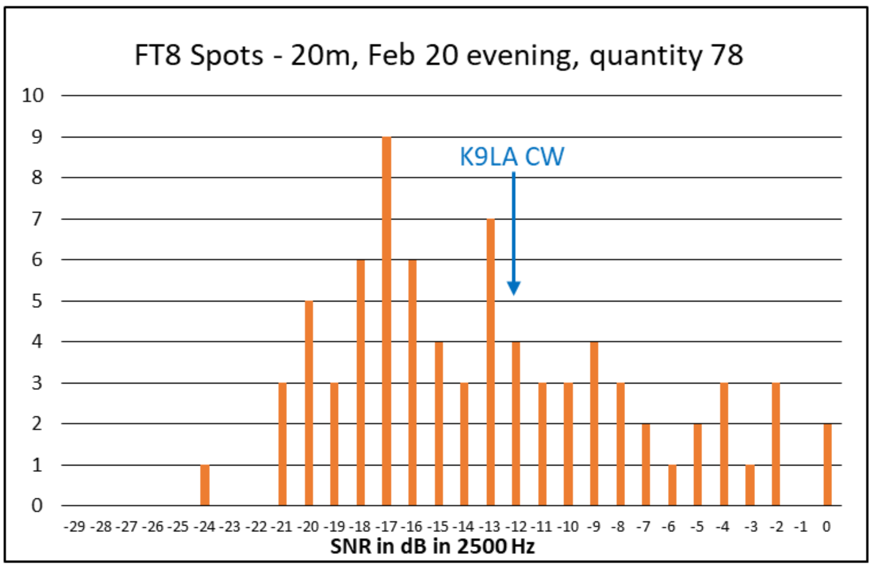
mode	bandwidth	probability	SNR threshold
JT65	2500 Hz	100%	-23 dB
FT8	2500 Hz	100%	-19 dB
CW (K9LA)	2500 Hz	100%	-12 dB

It's obvious to see that JT65 has a theoretical advantage of 11 dB over my ability to copy CW in a 250 Hz bandwidth. Similarly, FT8 has an advantage of 7 dB over my ability to copy CW in a 250 Hz bandwidth.

<u>Real-World Advantage of JT65 and FT8 over CW</u>

The previous section was purely theoretical. What happens in the real world? Does interference from other JT65/FT8 stations and other issues degrade the theoretical advantage? One way to assess this is to start looking at JT65 and FT8 spots with reported SNR values. This comes from the web site **hamspots.net**. Here are 20-Meter results from the evening of February 20, 2018 with JT65 data first and FT8 data second.

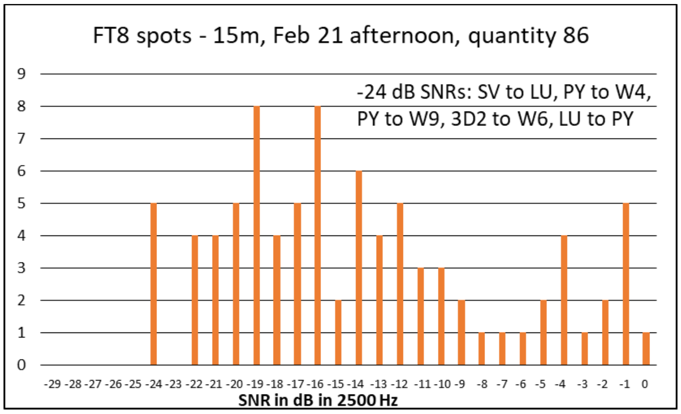


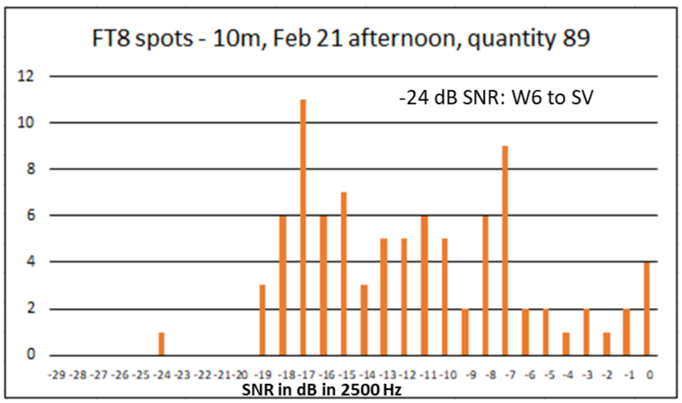


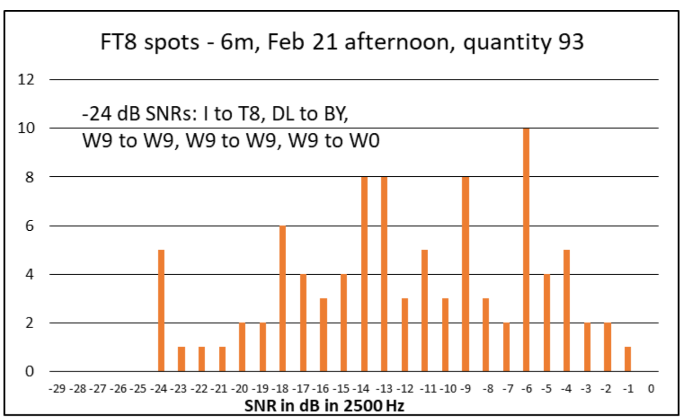
With the horizontal axes the same for both plots, it's easy to see that JT65 has an advantage over FT8. But we already knew that – it is reported to be 4 dB. My guess is that if the plots had many more samples, we could confirm that 4 dB is a good value for the JT65 advantage over FT8. The distributions also suggest that both modes in general are good down to an SNR a bit lower than what was cited in the tabular data in the previous section.

On the above two plots I've also annotated my ability to copy a CW signal at a -2 dB SNR in a 250 Hz bandwidth (equivalent to a -12 dB SNR in a 2500 Hz bandwidth). Thus JT65 offers a significant advantage and FT8 offers a sizeable advantage to my ability to copy CW.

Along this line, Jon Jones N0JK commented in his presentation at the 6-Meter BBQ in Austin, TX in September 2017 that a sharp CW operator with a radio with a good DSP algorithm could reduce the advantage of FT8 over CW. I agree with that. Jon also commented that a number of seasoned 6 Meter DXers feel CW hears as well or better than FT8. That's an interesting comment, and it ties into another of Jon's comments. He says that on 6m he doesn't see many FT8 SNR values that are less than -15 dB. I downloaded FT8 data on 15-Meters, 10-Meters and 6-Meters on the afternoon of February 21, 2018 to see if the SNR might show a frequency dependency. Here's that data.







My 6-Meter data has 25 QSOs (about one quarter of the total) with an SNR less than -15 dB. Something is going on between Jon's observations and my data – more investigation is needed.

Finally, check out the March 2018 BONUS Monthly Feature. It analyzes a 6-Meter FT8 QSO at a very low SNR.